Prehospital Tourniquet Use in Operation Iraqi Freedom: Effect on Hemorrhage Control and Outcomes

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Background: **Up to 9% of casualties killed in action during the Vietnam War died from exsanguination from extremity injuries. Retrospective reviews of prehospital tourniquet use in World War II and by the Israeli Defense Forces revealed improvements in extremity hemorrhage control and very few adverse limb outcomes when tourniquet times are less than 6 hours.**

Hypothesis: **We hypothesized that prehospital tourniquet use decreased hemorrhage from extremity injuries and saved lives, and was not associated with a substantial increase in adverse limb outcomes.**

Methods: **This was an institutional review board-approved, retrospective review of the 31st combat support hospital for 1 year during Operation Iraqi Freedom. Inclusion criteria were any patient with a traumatic amputation, major extremity vascular injury, or documented prehospital tourniquet.**

Results: **Among 3,444 total admissions, 165 patients met inclusion criteria. Sixty-seven patients had prehospital tourniquets (TK); 98 patients had severe extremity injuries but no prehospital tourniquet (No TK). Extremity Acute Injury Scores were the same (3.5 TK vs. 3.4 No TK) in both groups. Differences ($p < 0.05$) were noted in the numbers of patients with arm injuries (16.2% TK vs. 30.6% No TK), injuries requiring vascular reconstruction (29.9% TK vs. 52.5% No TK), traumatic amputations (41.8% TK vs. 26.3% No TK), and in those patients with adequate bleeding control on arrival (83% TK vs. 60% No TK). Secondary amputation rates (4 (6.0%) TK vs. 9 (9.1%) No TK); and mortality (3 (4.4%) TK vs. 4 (4.1%) No TK) did not differ. Tourniquet use was not deemed responsible for subsequent amputation in severely mangled extremities. Analysis revealed that four of seven deaths were potentially preventable with functional prehospital tourniquet placement.**

Conclusions: **Prehospital tourniquet use was associated with improved hemorrhage control, particularly in the worse injured (Injury Severity Score >15) subset of patients. Fifty-seven percent of the deaths might have been prevented by earlier tourniquet use. There were no early adverse outcomes related to tourniquet use.**

Key Words: **Tourniquet, Combat wounds, Extremity trauma, Explosion, Amputation, Vascular injury.**

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Hemorrhage from extremity injuries has been recognized in wars throughout history as the leading cause of potentially preventable death on the battlefield. Bellamy's landmark article on causes of death on the battlefield during the Vietnam War identified that 9% of potentially preventable battlefield deaths were from extremity hemorrhage.[1] Military surgeons from Operation Restore Hope in Somalia in 1993 similarly recognized a significant portion of hemorrhagic deaths from compressible hemorrhage.[2,3] Autopsy data from the current conflict confirms the previous findings.[4] These data and experiences have focused US military surgical research on the treatment of extremity and compressible hemorrhage for the decade leading up to Operations Enduring and Iraqi Freedom. Control of extremity hemorrhage has been identified as the top priority for prehospital combat casualty care providers.[5,6]

For the first time since the Vietnam War, US military casualties are occurring in numbers allowing the study of the prehospital treatment of life-threatening extremity hemorrhage. Although considerable evidence exists implicating extremity hemorrhage as a significant cause of potentially preventable death on the battlefield, relatively few clinical series specifically analyzing the effectiveness of tourniquets on hemorrhage control and casualty outcome have been published. In his article on tourniquet problems in war injuries from World War II, Wolff and Adkins concluded that properly applied extremity tourniquets reduced blood loss, were associated with low risk of complications, and saved lives.[7] In the most modern series to date of prehospital tourniquet use from the Israeli Defense Force's experience, Lakstein et al. demonstrated

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that the combination of aggressive tourniquet use training and guidelines with a rapid evacuation and trauma care system can prevent deaths from extremity hemorrhage with an acceptably low tourniquet-related complication rate.[8]

At the time of the initiation of the data collection for this study (July 2004), standardized tourniquets were just starting to be deployed into Afghanistan and Iraq, but a liberalized policy of tourniquet use—using a tourniquet as a first-line treatment for extremity hemorrhage in casualties under fire—although standard in the special operations arena, had not been widely disseminated through conventional forces. The purpose of this investigation was to analyze the employment of tourniquets at a single combat support hospital (CSH) in Iraq and determine the effect of tourniquets on extremity hemorrhage control and outcomes. We hypothesized that prehospital tourniquet use decreased hemorrhage from extremity injuries and saved lives, and was not associated with an increase in adverse limb outcomes (e.g., secondary amputation or neurologic deficits).

PATIENTS AND METHODS

A retrospective analysis was performed under Brooke Army Medical Center institutional review board-approved protocol #I.2005.178d. The analysis included all patients in whom a prehospital extremity tourniquet was used, all patients with traumatic extremity amputations (excluding partial amputations of foot, hand, or digits), and all patients with extremity vascular injuries (named vessel) who arrived at the 31st CSH between January 1 and December 31, 2004. Patients whose severe trunk or head injuries were thought to be the primary injury affecting outcome were excluded. The following data points were collected: age, sex, nationality, mechanism of injury, location of injury, documented extremity injury, associated injuries, presence of tourniquet, tourniquet time (minutes), operation performed (vascular reconstruction, vascular ligation without amputation, primary or debridement amputation), Injury Severity Score (ISS), Acute Injury Score for the Extremity, arrival physiologic parameters (heart rate [HR], systolic blood pressure [SBP], diastolic blood pressure, temperature, base deficit, pH, and hematocrit), blood products required (packed red blood cells, fresh whole blood, fresh frozen plasma, cryoprecipitate, rFVIIa), disposition (death, return to duty or discharge, evacuation), and length of stay (days). Assessment of extremity hemorrhage on arrival, scored simply as "active bleeding" or "no bleeding," was gained by review of patients' history and physical performed by the admitting surgeon or in some instances by direct interview with the surgeon involved. The primary outcomes measured were death, secondary amputation, and tourniquet-related complications. Follow-up data including additional procedures, complications, and outcomes on US soldiers evacuated out of theater were obtained via the Joint Theater Trauma Registry.

Patients with tourniquets were compared with those patients without tourniquets, first as a whole, then by matching patients for ISS >15, type of injury (patients requiring vascular reconstruction, patients requiring vascular ligations, patients requiring debridement amputations), and location of injury (forearm, arm, thigh, leg, multiple). Statistics were performed using SPSS Inc. version 11.0 software (SPSS Inc., Chicago, IL). Categorical data were compared using χ^2 analysis, with Fisher's exact test where appropriate. Continuous variables were compared using Student's *t* test.

RESULTS

Records from 3,444 patients in the 31st CSH database were reviewed. One hundred seventy-three (5%) patients were identified who suffered traumatic extremity amputation, major extremity vascular injury, or who had a prehospital tourniquet placed. Eight of these patients were excluded because they suffered significant or lethal trunk or head injuries, which were deemed to be the primary source of their arrival physiology, blood product requirements, and outcomes. Of the remaining 165 patients, 67 (40%) arrived at initial surgical care with prehospital tourniquet(s) in place and 98 (60%) arrived without prehospital tourniquets. Basic demographic data, mechanisms of injury, and mortality are shown in Table 1. Iraqi casualties, most of whom had received prehospital care from US military medics, were just as likely to get a tourniquet as US casualties.

A total of 80 tourniquets were placed on the 67 patients. Anatomic location of these tourniquets is shown in Figure 1. Of the subset of patients with multiple extremity injuries, 15 (22%) of the patients in the tourniquet group had a total of 34 limbs injured. A total of 28 tourniquets were applied on these patients. Six injured limbs in this treated group did not have tourniquets placed on them, three (50%) of which had vascular injuries. Only one of these untreated limbs had active bleeding on arrival. Fifteen (15%) patients in the no tourniquet group had 33 total limbs injured (p = NS compared with the tourniquet group). There were two deaths in each multiple extremity injury subset. Although there were more amputations in the group of patients who had tourniquets applied and more patients who had limb salvage in the group without

Table 1 Demographic Data and Mechanism of Injury

	Tourniquet N = 67 (%)	No Tourniquet N = 98 (%)	*p*
Age (yr)	28.5	25	<0.05
Sex			
Male	64 (97)	96 (96)	NS
Female	2 (3)	5 (4)	NS
Nationality			
Iraqi/non-US	28 (42)	37 (37)	NS
US soldier	39 (58)	62 (63)	NS
Mechanism			
Explosions	43 (64)	69 (70)	NS
GSW	20 (30)	27 (27)	NS
MVC	4 (6)	3 (3)	NS
Mortality	3 (4.4)	4 (4.1)	NS

NS indicates not significant.

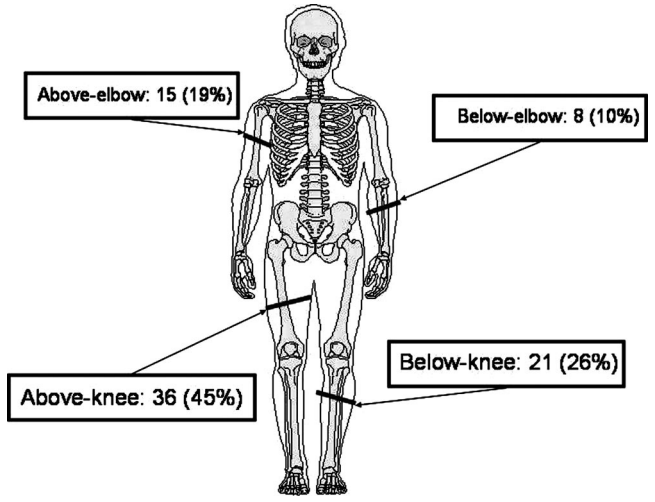

Fig. 1. *Location of prehospital tourniquets.*

tourniquets, these differences were not significant for this subset of patients.

For those patients who arrived with tourniquets, 41 (61%) had prehospital tourniquet times documented. Of these, the average tourniquet time was 70 minutes (range, 5–210 minutes). Other prehospital data, such as field vital signs, documentation regarding presence or absence of active bleeding, and other interventions performed were usually absent or otherwise so limited that they were not included in the analysis.

Analysis of Hemorrhage Control (Tourniquet Effectiveness)

Information regarding the presence or absence of active bleeding at the time of initial surgical care was available for 42 (63%) of the 67 patients with prehospital tourniquets and 28 (28%) of the 98 patients who arrived without prehospital tourniquets. Eighty-six patients (35 tourniquet, 51 no tourniquet) with ISS >15 were identified. Of these, 20 (57%) patients with tourniquets and 24 (55%) patients without tourniquets had documentation regarding status of hemorrhage control on arrival. Table 2 displays this data for all patients together, for only the patients with injuries that required primary or debridement amputations (e.g., nonsalvageable limbs), for only patients that has reconstructable vascular injuries, for those patients with upper extremity injuries, for those patients with lower extremity injuries, and for patients with ISS >15.

Of the 42 patients for whom documentation regarding tourniquet effectiveness was available, a total of 52 tourniquets were placed. Eight (15%) of these 52 tourniquets were documented as ineffective at controlling hemorrhage on arrival. Of these, four were above-knee (thigh) tourniquets, two were below-knee (leg) tourniquets, and two were below-elbow (forearm) tourniquets. Twelve (18%) of the patients in the tourniquet group had no documented vascular injury or major traumatic amputation. Based on the injuries treated in this group of patients, these tourniquets were nonindicated. However, prehospital provider observations regarding the extent of active bleeding in the field and the tactical situation were not available. One (1.5%) of the tourniquets was documented as incorrectly placed (i.e., placed distal to the wound). This incorrectly placed tourniquet was on 1 of the 12 casualties that did not have a documented major vascular injury or traumatic amputation. One other patient was noted to have extensive QuikClot in the wound distal to the tourniquet. This patient also did not have a major vascular injury or traumatic amputation. This patient's limb was salvaged.

Eleven tourniquets (14%) in six patients were documented to have controlled active hemorrhage on the patient's arrival to the trauma bay, but bleeding was noted to resume once active resuscitation of the casualty began. All of the tourniquets in which this rebleeding phenomenon was noted were placed in an above-knee location.

Analysis of Tourniquet Use Based on the Type of Injuries Sustained

Numbers and percentages of patients with injuries requiring vascular reconstruction and primary or debridement amputation are listed for each group (tourniquet vs. no tourniquet) in Table 3.

Distribution of limbs injured is shown in Table 4. Significantly more patients with arm injuries arrived to the level of surgical care without a tourniquet than with a tourniquet ($p = 0.02$). Eighteen of 30 (58%) patients who arrived without arm tourniquets had brachial artery injuries which required reconstruction, and 8 (27%) of them had traumatic amputations.

Table 2 **Bleeding Control, Tourniquet vs. No Tourniquet**

	Tourniquet (%)	No Tourniquet (%)	p^*
No bleeding on arrival	83.3	60.7	0.033
No bleeding on arrival (injuries requiring primary or debridement amputations)	92	50	0.058 (NS)
No bleeding on arrival (reconstructable vascular injuries)	69	60	0.456 (NS)
No bleeding on arrival (upper extremity injuries)	85	40	0.037
No bleeding on arrival (lower extremity injuries)	83	72	0.308 (NS)
No bleeding on arrival (ISS >15)	85	17	<0.0001

* Fisher's exact test.
NS indicates not significant.

Table 3 Numbers and Percentages of Patients With Injuries Requiring Various Surgical Interventions by Group (Prehospital Tourniquet vs. No Prehospital Tourniquet)

Injury	Tourniquet (%)	No Tourniquet (%)	*p*
Reconstructable vascular injury	20 (29)	52 (52)	0.004
Required debridement amputation*	28 (42)	25 (25)	0.022

* Patients in this group had traumatic amputations or mangled extremities that were deemed unsalvageable.

Table 4 Distribution of Limbs Injured

Location of Injuries	Tourniquet (n = 67) (%)	No Tourniquet (n = 98) (%)	*p*
Arm	11 (16)	30 (30)	0.02
Forearm	8 (6)	10 (10)	NS
Above-knee (thigh)	14 (22)	23 (22)	NS
Below-knee (leg)	19 (28)	20 (20)	NS
Multiple	15 (22)	15 (15)	NS

NS indicates not significant.

Table 5 Mean Arrival Physiologic Parameters

Physiologic Parameter	Tourniquet SD	No Tourniquet SD	*p*
SBP	108 ± 36	108 ± 32	NS
DBP	58 ± 21	60 ± 19	NS
HR	102 ± 35	101 ± 31	NS
Temp (F)	97 ± 3	97 ± 2	NS
Hematocrit	31 ± 10	32 ± 8	NS
pH	7.26 ± 0.1	7.26 ± 0.4	NS
Base deficit	6 ± 7	6 ± 5	NS
ISS	16.8 ± 14	17.5 ± 14	NS
AIS-extremity	3.5 ± 1.1	3.4 ± 1.0	NS

NS indicates not significant.

Mean arrival physiologic parameters for all patients are listed in Table 5. Mean arrival physiologic parameters for patients with ISS >15 are shown in Table 6. The only significant difference in these parameters between patients who arrived with prehospital tourniquets and those who arrived without tourniquets was the mean Acute Injury Score-extremity score in patients with ISS >15 was higher in the group with prehospital tourniquets placed.

Mean total blood product requirements (for the entire stay at 31st CSH) for all patients are listed in Table 7. Mean total blood requirements for patients with ISS >15 are shown in Table 8.

Mortality

Three of 67 (4.4%) patients with tourniquets versus 4 of 98 (4.1%) without tourniquets died (p = NS). Descriptions of these cases follow:

Table 6 Mean Arrival Physiologic Parameters, Patients With ISS >15

Physiologic Parameter	Tourniquet SD	No Tourniquet SD	*p*
SBP	94 ± 42	98 ± 38	NS
DBP	49 ± 23	53 ± 22	NS
HR	110 ± 39	108 ± 36	NS
Temp (F)	97 ± 3	97 ± 2	NS
Hematocrit	26 ± 10	28 ± 9	NS
pH	7.18 ± 0.2	7.24 ± 0.1	NS
Base deficit	9 ± 8	8 ± 5	NS
ISS	25.8 ± 14	26.7 ± 14	NS
AIS-extremity	4.4 ± 0.2	4.0 ± 0.2	0.027

NS indicates not significant.

Table 7 Mean Units of Blood Products Administered

Product	Tourniquet SD	No Tourniquet SD	*p*
PRBC	8.8 ± 9	7.2 ± 7	NS
FWB	1.6 ± 4	0.8 ± 2	NS
FFP	2.6 ± 3	2.2 ± 3	NS
Cryoprecipitate	2.4 ± 5	1.4 ± 4	NS

NS indicates not significant.

Table 8 Mean Units of Blood Products Administered, Patients With ISS >15

Product	Tourniquet SD	No Tourniquet SD	*p*
PRBC	13 ± 9	10 ± 8	NS
FWB	2.6 ± 5	1.3 ± 3	NS
FFP	4 ± 3	3 ± 4	NS
Cryoprecipitate	4.1 ± 6	2.0 ± 4	NS

NS indicates not significant.

Deaths in Casualties With Tourniquets

Patient 1. A 37-year-old man sustained bilateral upper extremity burns, near amputation of right lower extremity just below level of groin, and a left calf crush injury from an improvised explosive device. He had a tourniquet placed in the right groin, but no comments on effectiveness of tourniquet were available. The patient arrived undergoing CPR and was declared dead in the ER shortly thereafter.

Patient 2. A 28-year-old man sustained bilateral mangled lower extremities from proximal thighs to feet, traumatic right trans-humeral amputation, and fragment injury to left brachial artery with active bleeding and a pulseless limb from an improvised explosive device. Prehospital tourniquets had been applied to both groins and the right arm and no bleeding was noted from these injuries on arrival. No tourniquet had been placed proximal to left arm arterial injury. Once resuscitation began (in the operating room [OR]), the right arm tourniquet was noted to maintain hemorrhage control but some bleeding resumed through the thigh tourniquets, which

was controlled surgically in the OR. Prehospital data and tourniquet times were not available. The patient was also noted to have a pelvic fracture and pelvic and retroperitoneal hematoma at time of abdominal exploration. On arrival his SBP was 30, HR was 146, pH was 6.5, hematocrit was 27, and his base deficit was 30. The patient underwent damage control abdominal exploration with packing of the abdomen and rapid control of the iliac arteries, followed by bilateral above-knee amputations, debridement amputation of the right arm, and vascular shunt placement in left brachial artery. The patient died in intensive care unit shortly after operation secondary to irreversible shock or physiologic exhaustion.

Patient 3. A 35-year-old man sustained bilateral mangled legs from an improvised explosive device. Improvised tourniquets were applied just above the knees (cravat and stick on one side, cravat and jack-knife on the other) at a battalion aid station. Blood pressure at the Battalion Aid Station was 76/24. Patient had a 30-minute tourniquet time before his arrival to the CSH. On arrival, the tourniquets were noted to be too loose to control hemorrhage (fingers could be slipped easily under the tourniquets). The patient's arrival SBP was 68, HR was 142, pH was 6.8, hematocrit was 19, and base deficit was 25. The patient had tourniquets manually tightened, then replaced with pneumatic tourniquets, and was moved to the OR. He underwent rapid bilateral through-knee amputations for hemorrhage control, but died shortly thereafter of irreversible shock or physiologic exhaustion.

Deaths in Casualties Without Tourniquets

Patient 4. A man of unknown age sustained a right mid-hand amputation and bilateral mangled lower extremities below the level of the mid-thigh from an improvised explosive device. No prehospital data were available. The patient arrived without any tourniquets applied. He was declared dead on arrival.

Patient 5. A man of unknown age sustained an open left humerus fracture and brachial artery disruption from a gunshot wound. He was taken initially to a forward surgical team. No prehospital tourniquet had been placed. His arrival SBP was 66, HR was 92, temperature was 90.8, pH was 7.3, and base deficit was 7. He underwent reconstruction of his brachial artery with a prosthetic interposition graft at the forward surgical team, which had to be revised at the CSH to a reversed autologous saphenous vein graft. The patient died of sepsis on postinjury day 11.

Patient 6. A 22-year-old man sustained multiple fragment wounds to all four extremities with a left popliteal artery injury, a closed head injury, and ~10% body surface area burns to his back from a mortar attack. No prehospital tourniquet was applied. He was taken initially to another CSH, where a base deficit of 8 was documented. No tourniquet was applied, and the patient was transferred to the 31st CSH for neurosurgical evaluation. His arrival SBP was 60, HR was 153, pH was 7.29, hematocrit was 28, and base deficit was 14. The patient died in the OR from irreversible shock or physiologic exhaustion during surgical treatments including attempted repair of the popliteal artery injury.

Patient 7. A man of unknown age sustained a left grade IIIB open femur fracture and transection of profunda femoral artery secondary to a gunshot wound. No prehospital tourniquet was applied. His arrival SBP was 97, HR was 92, pH was 7.23, and base deficit was 11. The patient underwent external fixator placement of his femur and ligation of his profunda femoral artery. He required secondary amputation for the development of necrotizing fasciitis in the thigh and eventually died of sepsis or MODS.

Independent review of the seven deaths by an expert panel identified that four of the seven deaths were potentially preventable with use of properly placed and functional extremity tourniquets.

Follow-up and Analysis of Tourniquet-Related Complications

Follow-up data were available for 52% of US casualties. No late deaths were noted. Average follow-up was 47 days for US casualties and 10 days for non-US casualties. Secondary amputations (after initial limb salvage) at the CSH or after evacuation from the CSH were required for a total of 13 patients; 4 (6%) in the group who received prehospital tourniquets and 9 (9%) in the group that did not (p = NS). There were no identified complications related specifically to tourniquet use, and no late neurologic injuries that could be clearly related to a tourniquet use were documented.

DISCUSSION

Analysis of Special Operations Forces casualties killed in action during the Global War on Terrorism (2001–2004) revealed that 13% of those casualties who had potentially survivable injuries died of hemorrhage amenable to a tourniquet.[4] In a separate, unpublished analysis of 35 casualties who died of only isolated extremity injuries early (2001–2004) in the Global War on Terrorism, 18 (51%) of these deaths were potentially preventable with the use of an extremity tourniquet. It should be noted that the tactical situations and medical capabilities at the scenes of these casualties is unknown (John Holcomb, MD, June 2007, personal communication).

Although our data did not show a survival benefit for prehospital tourniquet use, it is biased toward those patients that survived evacuation off the battlefield to the CSH. We were unable to obtain data on casualties that died before reaching surgical care during the study time period. Our data demonstrate that the use of a tourniquet is associated with improved hemorrhage control for severely injured patients sustaining major extremity vascular injuries or traumatic amputations. Furthermore, we encountered no significant adverse sequelae related to prehospital tourniquet use. The absence of neurologic complications in our dataset may be related to the relatively short prehospital tourniquet times documented (mean, 70 minutes).

This data coincides well with previously published reports.[7,8] To date, the most detailed case series analyzing tourniquet use on the battlefield is Lakstein et al.'s article documenting the experience of the Israeli Defense Force Medical Corps.[8] These researchers reviewed 550 cases of soldiers treated in the prehospital setting, 91 of whom were treated with a tourniquet. They documented a high rate of nonindicated tourniquets (47%), indicating liberal guidelines for tourniquet use. Notably, no deaths from extremity hemorrhage and a low neurologic complication rate (5.5%) were documented in their series. The few neurologic complications were all in casualties whose tourniquet times were 109 minutes to 187 minutes. Our nonindicated tourniquet rate of 18% reflects a comparatively conservative employment of prehospital extremity tourniquets in the early part of the war. Ongoing analysis is expected to show that the nonindicated tourniquet rate has risen since deployment of individual tourniquets to each soldier and dissemination of doctrine liberalizing their use.

In Wolff and Adkins's analysis of "200 random cases" of tourniquet use during the Italian campaign (1941–1943), no tourniquet-related complications were noted for a 5- to 10-day observation period after a tourniquet application between 2 hours and 4 hours. However, little clinical data aside from illustrative case reports were presented.[7] In their article, Wolff and Adkins also recognized short-comings in training, application, and management of tourniquets by both prehospital and hospital personnel and made recommendations regarding the management of tourniquets, including the dictum that tourniquets not be removed or intermittently loosened before arrival to surgical care. Wolff and Adkins's conclusions and recommendations for tourniquet management were authoritative (and still relevant today) by virtue of the experiences documented, which included treatment of over 1,000 amputation patients by his auxiliary surgical group.

Despite these aforementioned published clinical data compiled by military researchers and the anecdotal experience of military surgeons supporting prehospital tourniquet effectiveness, prehospital tourniquet use remained controversial for many years.[9,10] Employment of tourniquets by civilian prehospital services was abandoned over largely unfounded concerns of unacceptably high rates of limb loss or neurologic injuries related to tourniquet use. In addition, the concern that improperly applied tourniquets would increase hemorrhage from nonamputated limbs with vascular injuries by creating a venous tourniquet effect contributed to this reluctance to use prehospital tourniquets in civilian emergency settings. This condemnation of tourniquets as instruments, which cause more harm than good is somewhat difficult to understand in light of considerable clinical evidence demonstrating tourniquet safety when used appropriately in elective operative settings.[11]

A final reason for not employing standard prehospital tourniquets in civilian trauma settings may stem from the perception that exsanguinating extremity hemorrhage from civilian trauma mechanisms is relatively uncommon, prehospital times are short, and direct pressure or an improvised tourniquet can be applied in the rare instances when uncontrolled extremity bleeding is present. Indeed, a recent study by Dorlac et al. revealed that there are relatively low numbers of civilian deaths from extremity hemorrhage; however, in 57% of the cases analyzed, the hemorrhage site would have been amenable to control with a tourniquet.[12] Based on Dorlac et al.'s study, the Israeli Defense Forces study, and recent experiences from Operations Enduring and Iraqi Freedom, some civilian EMS services are beginning to carry extremity tourniquets on ambulances.

This historical reluctance to use tourniquets for control of extremity hemorrhage was still present in military prehospital providers early in Operation Iraqi Freedom and at the time of this study. Our data shows that patients with major vascular injuries and patients with arm injuries were less likely to have a prehospital tourniquet placed. The underutilization of tourniquets in these subsets of patients may be related to lack of clinical signs of hemorrhage (for example, a patient with a major vascular injury but a contained hematoma), ability to obtain hemorrhage control with other means (e.g., pressure dressing on an arm injury), or reluctance in the prehospital provider to place a tourniquet on an upper extremity for fear of ischemia and resultant limb loss. This has implications for medic training, particularly given our finding that patients with injuries amenable to vascular reconstruction were less likely to have a tourniquet applied. Anecdotal reports of soldiers dying from isolated vascular injuries amenable to a tourniquet have been published in national media outlets.[13]

Research evaluating possible battlefield tourniquet systems began before the Global War on Terrorism. Calkins et al., through surveys and device testing by Special Operations corpsmen, established 15 specific criteria regarding the effectiveness, simplicity, ruggedness, and portability of battlefield tourniquet systems.[14] Walters et al. at the United States Army Institute of Surgical Research (USAISR) performed a systematic evaluation of the effectiveness of commercially available prehospital tourniquets in human volunteers,[15] with the goal of identifying a standard tourniquet to provided to soldiers and medics on the battlefield. This study identified three products that were able to reliably occlude arterial blood flow (as measured by Doppler signal) in 100% of volunteers. Two of these products, the Special Operations Forces Tactical Tourniquet (Tactical Medical Solutions, LLC) and the Combat Application Tourniquet-1 (North American Rescue Products, Inc.), both light-weight, compact, modular versions of the Spanish windlass tourniquet, have been deployed to combat zones as individually issued hemorrhage control devices. Each soldier carries his or her own tourniquet, and unit medics are supplied with additional numbers of these devices in their aid bags. Over 400,000 of these devices were deployed into combat theaters at the time of this writing (John B. Holcomb, MD, personal communication). The USAISR has recommended that a third tourniquet, the Emergency and

Military Tourniquet (EMT, Delfi Innovations, Inc.) be deployed for placement in evacuation vehicles, battalion aid stations, and emergency departments.

Based on the data presented herein, the US Army Surgeon General published an All Army message in March 2005, recommending that all soldiers carry tourniquets.

Current military doctrine dictates the use of a tourniquet as first line treatment for all "life-threatening" extremity hemorrhage during the first stage of Tactical Combat Casualty Care, that portion of care that occurs although the casualty is under active fire. Only when the casualty has been evacuated from active direct or indirect fire may the tourniquet be reassessed. First, a pressure or hemostatic dressing is applied to the wound and the casualty is resuscitated if needed. Hemodynamically unstable casualties or casualties with decreased mental status should not have the tourniquet loosened in the field. Stable and mentating casualties with injuries that appear less severe may have the tourniquet loosened with a period of direct observation. If bleeding resumes, the tourniquet should be tightened and the patient evacuated. The tourniquet should only be loosened by a medical officer in this case. If the hemorrhage control can be maintained with another method (e.g., pressure dressing), the tourniquet can remain loosened but should be frequently monitored. If this monitoring is not possible, continued use of the tourniquet should be preferred over the risk of unnoticed rebleeding.[16]

The observed result of this doctrinal change is that most casualties with extremity injuries are now arriving to the level of surgical care with a tourniquet in place (Matthew J. Martin, MD, Scott R. Steele, MD, August 2006, personal communications). This observation is corroborated by the large numbers of casualties arriving with prehospital tourniquets identified in a ongoing study (John Holcomb, MD, John F. Kragh, MD, February 2007, personal communication).

Limitations

Several limitations to this dataset are apparent, many of which are common to combat casualty care research projects. The data are retrospective and from a single hospital. There is very little prehospital data; for example, almost 40% of casualties who had prehospital tourniquets applied do not have tourniquet times documented. There is essentially no data available regarding the tactical environment in which the tourniquet was applied. Such factors as delays in casualties receiving first responder care and delays in evacuation related to ongoing combat or tactical needs will affect outcome in some patients. Interviews with first responders to obtain data regarding the appearance of the casualties' wounds and the presence or absence of arterial or venous bleeding were not possible primarily because of the operation tempo of both the combat units and the CSH. Times from injury to arrival at hospital were not available, and data from echelon 1 (battalion aid stations) and echelon 2b facilities (forward surgical teams) was frequently incomplete or absent.

Data on the presence or absence of bleeding is only available in 28% of the patients that did not receive prehospital tourniquets. This may have been because of the tempo of operations, or possibly surgeons were less likely to document a negative finding compared with a positive finding. Hence, many of the patients in the group that did not receive tourniquets may not have had bleeding on arrival, and this could introduce a bias in the analysis of the effectiveness of tourniquets on hemorrhage control. It should in fact be noted that the group of patients that had tourniquets applied and the ones that did not are indeed different groups. More patients that required debridement amputations were found in the tourniquet group, and more patients that had injuries amenable to vascular reconstruction were seen in the group without tourniquets.

This difference is likely related to the physical findings that would prompt a medic to place a tourniquet. Patients who required primary or debridement amputations frequently had dramatic appearing traumatic amputations (Fig. 2), mangled extremities (Fig. 3), or severe soft tissue components to their wounds (Fig. 4). Patients with reconstructable vascular injuries were more likely to have less soft tissue and bony destruction and contained hematoma without active bleeding (Fig. 5). Hence, medics were less likely to place a tourniquet on these injuries.

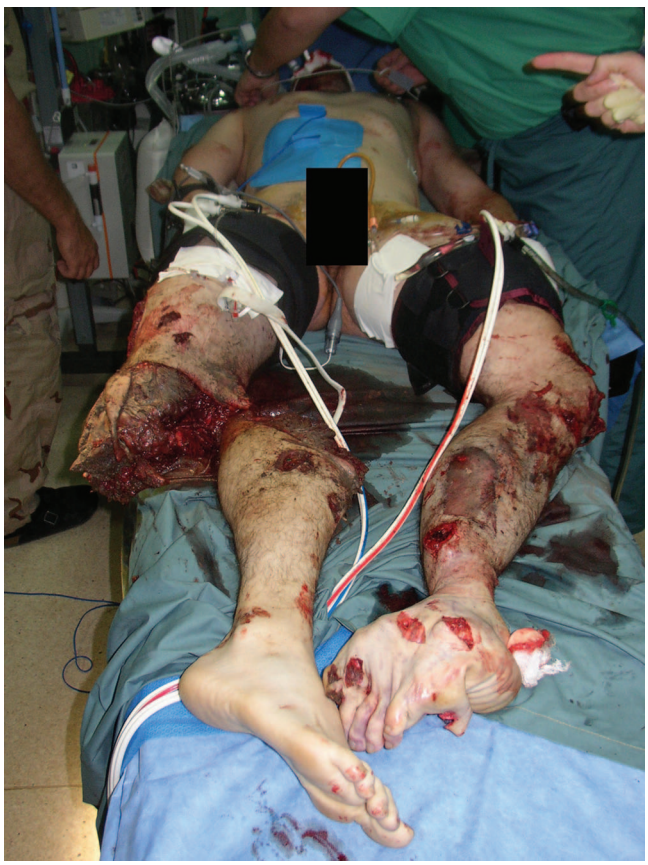

Fig. 2. *Patient with traumatic amputation on right and mangled leg on left, controlled with pneumatic tourniquets.*

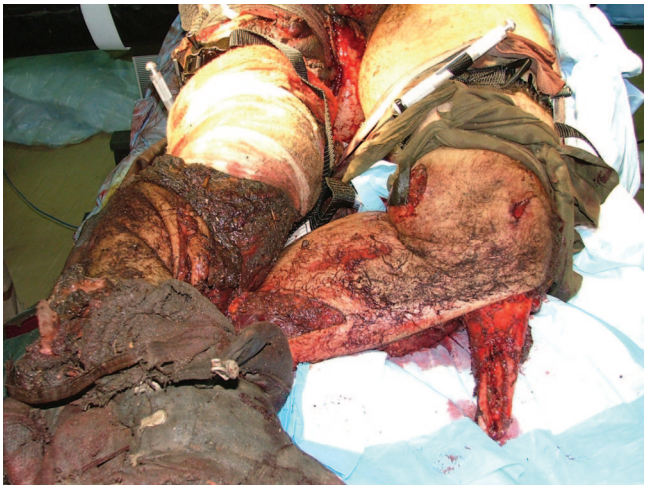

Fig. 3. *Patient with bilateral mangled lower extremities/traumatic amputations, hemorrhage controlled with Special Operation Forces Tactical Tourniquet (SOFTT).*

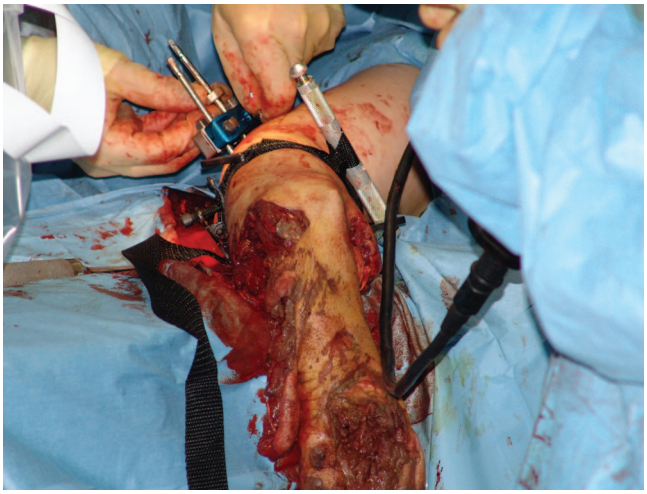

Fig. 4. *Patient with severe soft tissue and bony injuries to right forearm/hand, hemorrhage controlled with Special Operation Forces Tactical Tourniquet (SOFTT).*

Recommendations

1. Liberalized use of prehospital tourniquets as a first-line treatment for extremity hemorrhage should continue.
2. Prehospital providers and treating surgeons should be cognizant of the possibility of failure of the tourniquet to control hemorrhage, particularly at the above-knee level.
3. To avoid rebleeding or bleeding through a prehospital tourniquet, treating surgeons should replace prehospital tourniquets with pneumatic tourniquets before resuscitation or as soon as possible after casualty arrival to the level of surgical care.
4. Further study of military prehospital tourniquet use is ongoing and should continue. Future studies should examine effectiveness of various types of tourniquets, effect on survival, incidence of neurologic injury, and ischemia-related complications.
5. Civilian prehospital providers should consider the portable pneumatic tourniquets as a first-line treatment for life-threatening extremity hemorrhage.

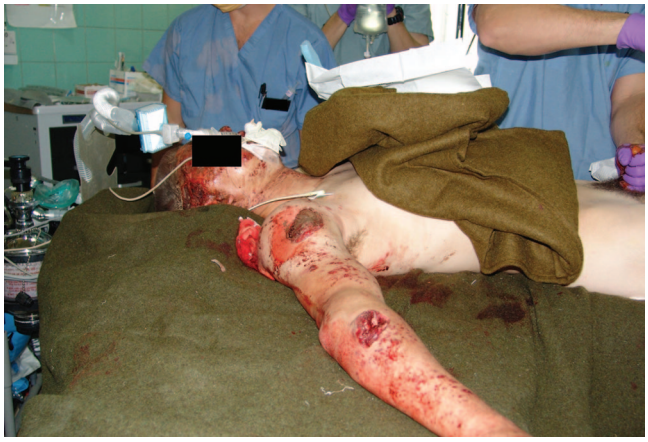

Fig. 5. *Patient with multiple fragment wounds to right upper extremity. Brachial artery and vein were transected but contained in a hematoma.*

CONCLUSIONS

Prehospital tourniquet use is an effective means of establishing extremity hemorrhage control in military casualties. Tourniquet use is associated with low risk of ischemia-related complications or neurologic injury. Although no survival benefit of tourniquet use could be demonstrated with these data, it is likely that ongoing and future analyses will include those casualties who die before reaching surgical care and will demonstrate a survival benefit associated with tourniquet use.

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DISCUSSION

Dr. James R. Ficke (Brooke Army Medical Center, Fort Sam Houston, TX): This study, by several experienced trauma surgeons, who deployed into a combat theater of operations, represents several critical landmarks in far forward surgical and trauma research. They are to be commended for this effort. First, this may well represent the first institutional review board-approved protocol conducted while engaged in the front line far forward care of the wounded. Additionally, this research provides a baseline frame of reference for future study of the impact of a radical change in battlefield care of the wounded. Specifically, the retrospective study examined short-term outcomes of tourniquet use before universal issue of this device; widespread training on its use; and development of a comprehensive theater trauma registry and reliable electronic medical records. Finally, the results of this study directly impacted the acquisition of technology specifically directed at improving survival outcomes early enough that this intervention can be readily quantified and evaluated.

The authors describe a review of 3,444 trauma patients receiving resuscitation at the busiest CSH in Iraq during a single unit's deployment. Their clear hypothesis stated that prehospital tourniquet use decreased hemorrhage from extremity injuries and saved lives and was not associated with an increase in adverse limb outcomes. Inclusion criteria were well described and included every patient who sustained at least one major limb amputation; a major extremity vascular injury; or a documented prehospital tourniquet applied. Exclusion criteria were those patients whose primary injury was severe head or trunk, although these eight patients may have also had severe associated extremity injuries or compressible hemorrhage or both. Record review was reliably available for only 57% of patients arriving with tourniquets and 55% of those without prehospital tourniquets regarding effectiveness. Also, follow-up data were only available on 52% of these casualties, making longer-term complication evaluation difficult. This speaks to the imperative of reliable medical record documentation, which was not fully in place at that time. In the patients whom had documentation, 15% with tourniquets in place were not effective, and had continued hemorrhage. Additionally, 11 tourniquets demonstrated no hemorrhage on arrival, but resumed hemorrhage upon resuscitation. This has been observed in other locations, personally, and may reflect under-resuscitation with resultant peripheral vascular shunting. In total, then, 19 of 52 prehospital tourniquets were not effective in hemorrhage control before damage control surgery. This amplifies the need for adequate training in prehospital tourniquet application.

The authors found that 18 of 30 patients without arm tourniquets did in fact require vascular reconstruction, and another 8 had amputations. In a similar trend, 28 of 67 (42%) arriving with a tourniquet underwent amputation, versus 25 of 98 not arriving with a tourniquet who also had unsalvageable limbs. These observations led them to a conclusion that a less visibly severe injury was also less likely to have a prehospital tourniquet placed, regardless of hemorrhage or associated vascular injury. In addition, placement of tourniquets on the upper extremity was significantly less frequent despite vascular injury. Traditional teaching has been that tourniquet application is a last resort, and loss of upper extremity is also less preferable. This appears to be false, and underscores the need for a paradigm shift in tactical combat casualty care. In their words, "historical reluctance to use tourniquets for control of extremity hemorrhage" was still present. Placement of a tourniquet is not in itself a significant risk for loss of limb. In their discussion, the authors cite Dorlac et al.,[1] who examined 14 of 75,000 trauma patients. They concluded that 8 of 14 had compressible hemorrhage that was potentially preventable with prehospital tourniquet application. Neither study could reach a decisive conclusion, but the seven cases described above provide a convincing argument.

This article identified the effect of hemorrhage control in prehospital application of tourniquets in a combat setting. Over 80% of injuries seen in this environment are penetrating, and over 60% occur to the extremities.[2] Therefore, the authors' recommendation for liberalized use of prehospital field tourniquets is valid, and universal soldier-level training for application is warranted. Additionally, the grave consequences of ineffective application or failure of the device merits awareness, as they noted here. However, a recommendation to replace previously applied devices with pneumatic methods was not discussed. In a review of elective tourniquet use for orthopedic surgery by Wakai et al.,[3] the pneumatic tourniquet was found to be safe, and effective. However, this may not apply to the trauma setting, and does not necessarily warrant routine replacement of prehospital devices. Rather, judicious assessment and augmentation may provide similar effect without additional application trauma and hemorrhage.

Finally, with a 52% follow-up rate, support for the hypothesis of low adverse limb outcomes cannot be supported. However, this provides a sound baseline for future directed study.

This study has contributed a great deal, and will undoubtedly serve as a foundation for a comparative study after universal training and distribution of the field tourniquets. Over 400,000 field tourniquets have now been distributed into the combat zone. The Joint Theater Trauma Registry now captures data on prehospital application, duration of ischemic time, injury severity parameters, and complication data back into the continental United States through the evacuation channels. There exists a significant need for study after the massive distribution and training effort on the combat application of a field tourniquet to document effectiveness, complications, and actual quantification of lives saved. I applaud the authors on their relentless pursuit of this data under the austere conditions of a combat support hospital.

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Dr. Alec C. Beekley (Department of General Surgery, Madigan Army Medical Center, Fort Lewis, WA): I thank Dr. Ficke for his balanced and constructive review of our article from the perspective of an orthopedic surgeon with extensive experience in both civilian and military extremity trauma. His comments serve to highlight the strengths and weaknesses of our data and will assist in directing future research on prehospital tourniquet use in both military and civilian settings.

Some of the challenges to performing a retrospective chart review to analyze a prehospital intervention in a busy combat support hospital were noted by Dr. Ficke. Specifically, he noted that data on tourniquet effectiveness or the presence or absence of hemorrhage on arrival was only available on just over half of the casualties. Surgeons' notes on critically injured casualties were often by necessity brief and to the point (e.g., "History: Soldier with blast injuries to all extremities; unstable; tourniquets applied; Plan: to OR."). This emphasizes the need for prospective data collection, ideally by personnel not directly involved in the patient's care. The Deployed Combat Casualty Research Team has performed just such data collection on tourniquet use in the last 12 months. Research personnel were at the bedside in the trauma bay on each casualty that arrived with a prehospital tourniquet to document valuable data regarding injuries, tourniquet location, type and number of tourniquets used, effectiveness, times, physiologic data, and to photograph the injured limb(s). Over 700 patients and close to 1,000 tourniquet applications have been recorded in this fashion. Analysis of this data will undoubtedly answer many of the questions our data was unable to answer.

Dr. Ficke also noted that follow-up data was only available on 52% of patients, and we agree that it is difficult to draw definitive conclusions regarding tourniquet complications because of this. The imperfect data we do have, combined with our own observations, allows us to form opinions on the safety and complication profile of prehospital tourniquets, but we agree with the reviewer that it is important to state them as such.

Finally, in response to Dr. Ficke's comments on the use of pneumatic tourniquets to replace prehospital tourniquets, I agree with the concept that augmentation of a prehospital tourniquet may be a better strategy where feasible. Our study group found that the prehospital tourniquets most likely to provide inadequate hemorrhage control during resuscitation were in the proximal thigh location, and we frequently found that there was simply no room on the extremity between the wound and the prehospital tourniquet or between the prehospital tourniquet and the torso to add an additional pneumatic tourniquet for augmentation. Using a two-person technique, we found we were able to replace inadequate field tourniquets with robust, wide operating room pneumatic tourniquets in a rapid fashion with little additional blood loss. The broader take-home lesson from this discussion is that prehospital tourniquets must be checked for adequacy on arrival of the casualty and rechecked frequently during resuscitation to avoid unnecessary continued blood loss. The few minutes spent on augmentation or replacement of an inadequate prehospital tourniquet will be minutes well spent.